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FORAMINIFERA FROM THE TYPE AREA OF THE KREYENHAGEN SHALE OF CALIFORNIA

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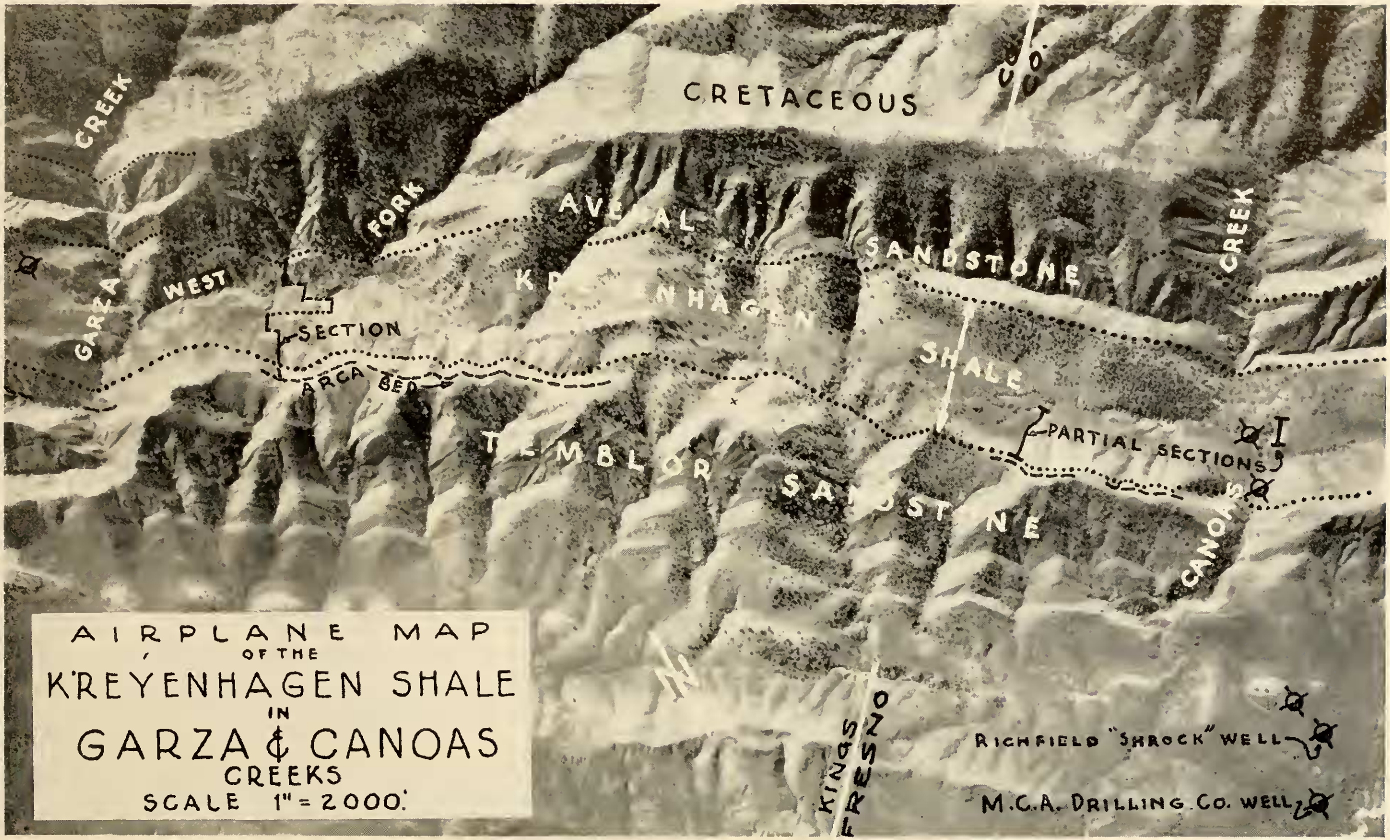
AIRPLANE MAP
OF THE
KREYENHAGEN SHALE
IN
GARZA & CANOAS
CREEKS
SCALE 1" = 2000'
CRETACEOUS
CREEK
FORK
WEST
GARZA
SECTION
ARCA BED
SANDSTONE
SHALE
PARTIAL SECTIONS
TEMBLOR
CANOAS
KINGS
FRESNO
RICHFIELD "SHROCK" WELL
M.C.A. DRILLING CO. WELL

FORAMINIFERA FROM THE TYPE AREA OF THE KREYENHAGEN SHALE OF CALIFORNIA[1]

BY

J. A. CUSHMAN AND S. S. SIEGFUS

CONTENTS

ABSTRACT

From twenty selected samples, the authors list sixty species of foraminifera from the Kreyenhagen shale at Garza Creek. This locality is better exposed than and compares favorably with the type locality at Canoas Creek, originally designated by F. M. Anderson in 1905. An additional twenty-two species are listed from the lowermost Canoas siltstone member, from two other Reef Ridge localities near Little Tar Canyon and one other locality in Oil Canyon, north of Coalinga. Twenty-four new species first found in the Kreyenhagen shale are described and figured. The rest of the species shown on the check-list are figured and briefly discussed. An airplane photograph shows the proximity of Garza Creek and Canoas Creek, and indicates where the generalized section of the formation shown in the paper was measured. A comparison of the two localities is made and reasons given for considering them together as the "type area."

Since the upper and lower limits of the formation were not definitely described by Anderson, these limits are more clearly defined. The formation was divided lithologically into ten members (A to J inclusive), the lowest being the Canoas siltstone member, with its distinctive lithology and much discussed foraminiferal fauna. Although the Kreyenhagen is predominantly a brown silty shale, it includes, in the upper part, a sandy member (D) which can be traced some distance along Reef Ridge. Comparison is made of the foraminifera of the type area with other areas in California. Some age relationships of this fauna are also discussed.

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[1]Published by permission of the Director of the United States Geological Survey.

Introduction

The Kreyenhagen shale is one of the important Tertiary formations in California, extending over much of the central part of the State.[2] The identification of the formation and its correlation from place to place have been greatly disputed, however. As the fauna of the formation consists largely of Foraminifera, and as a standard of reference is needed for comparison with other areas, it has seemed desirable to establish as definitely as possible the sequence of lithologic units and of foraminiferal assemblages in the type area. It was with this project in mind that the junior author in 1932 began the field studies that have resulted in the data offered in this paper.

According to the original description of F. M. Anderson,[3] the type locality is at the "Kreyenhagen wells," on Canoas Creek in the central part of the Reef Ridge area, about 12 miles south of the town of Coalinga, Fresno County, and due west of the North Dome of the Kettleman Hills oil field. The field work was, therefore, at first confined to Canoas Creek, but it soon became apparent that this section would not yield all the information desired. Search in nearby areas showed that the most nearly complete section available was to be found in Garza Creek, 2½ miles southeast of Canoas Creek. The study was continued on Garza Creek, and in the present work the two localities together are considered the type area of the Kreyenhagen shale.

Acknowledgments

The writers wish to express their appreciation to Mr. C. C. Church of the Tidewater Associated Oil Company for assisting in this cooperative effort. Dr. Ralph Stewart of the Geological Survey presented material from the southern part of the Reef Ridge area which was useful in correlating the area with that north of Coalinga, and Mr. Ralph Richards, also of the Geological Survey, assisted in some of the earlier field work. To the Western States Gasoline Corporation and the Kettleman North Dome Association the junior author acknowledges assistance in the field work during this study. The aid of Boris Laiming, P. P. Goudkoff, and D. D. Hughes in connection with some of the occurrences is also acknowledged. Others to whom the authors are

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[2]Jenkins, O. P., Stratigraphic significance of the Kreyenhagen shale of California: Mining in California, vol. 27, no. 2, pp. 141-186, 1931.

[3]Anderson, F. M., A stratigraphic study of the Mount Diablo Range of California: California Acad. Sci. Proc., 3d ser., Geology, vol. 2, p. 163, 1905.

indebted are W. F. Barbat, Frank Tolman, Fred Menken, John Galloway, Art May, R. B. Hutcheson, and E. V. Winterer.

STRATIGRAPHY

Beside the paper by F. M. Anderson[4] in which the Kreyenhagen shale was named, the type area of the formation has been discussed in papers by Arnold and Anderson,[5] Hanna,[6] and Von Estorff.[7] The history of the typical Kreyenhagen and its correlations are briefly stated by Von Estorff.[8] It was at first considered Eocene and correlated with beds elsewhere that were also so assigned. Some of these other beds were later shown to be in part of Cretaceous age and in part possibly of Oligocene age. Some doubt has been thrown, therefore, on the age assignment of the type Kreyenhagen, as is set forth in later pages.

The Kreyenhagen is predominantly a hard brown silty shale. Because of its distinctive lithology, stratigraphic position, and foraminiferal fauna, it is recognizable over a large part of the San Joaquin Valley. Although the formation is hard and resistant at some places at the outcrop, as a whole it is decomposed, so that throughout most of its extent south of Coalinga it occurs as a soil-covered depressed belt of brown shale and sand between the Miocene Temblor sandstone to the northeast and the overhanging cliffs of the older Avenal sandstone to the southwest. This belt parallels the Kettleman Hills for about 20 miles from Zapato Creek on the northwest end, where it is overlapped, southeastward to a point near Little Tar Canyon, where it becomes involved in structural complications and is presumably also overlapped.

In the central part of the Reef Ridge area the Kreyenhagen shale is slightly less than 1,000 feet in thickness and dips about 55° in a northeasterly direction toward Kettleman Hills and the San Joaquin Valley. The upper part of the formation in this area is somewhat more sandy than elsewhere and is separated from the overlying Miocene sandstone by a rather inconspicuous unconformity. Because these upper interbedded sand and shale beds become overlapped in either direction from

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4Anderson, F. M., op. cit.

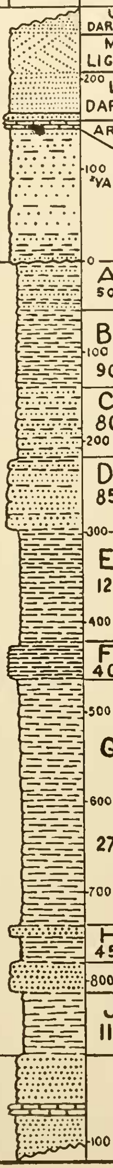
5Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, p. 68, 1910.

6Hanna, G. D., The Age and Correlation of Kreyenhagen Shale in California: Am. Assoc. Petroleum Geologists Bull., vol. 9, pp. 990-999, 1925.

7Von Estorff, F. E., Kreyenhagen shale at type locality, Fresno County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 1326, 1930.

8Von Estorff, F. E., op. cit., pp. 1321-1322.

SECTION OF THE KREYENHAGEN SHALE
AT GARZA CREEK, KINGS CO., CALIFORNIA
SHOWING CONTIGUOUS BEDS.



Age	Formation	Member	Lithology	Characteristic Fossils
Miocene	? Temblor	Upper dark sand	Medium to coarse dark gray, biotitic sand. Shows spherical weathering.	
		Middle light sand	Light colored, medium to coarse, cross-bedded sand. A few pebble beds in lower part.	
		Lower dark sand	Medium to coarse, biotitic sand. 1' Diatomite 10' above base.	Scutella sp. Diatoms, Nonion? casts.
		Arca bed	5'± Calcareous, concretionary ss. Arca common.	Arca osmonti, Pecten perrini, Sharks teeth, Phacoides.
		"Vaqueros (?) Sand	Massive light gray, fine-grained friable sandstone.	Sharks teeth.
?	Kreyenhagen Shale	A 50'	Thinly bedded brown, silty shale and fine- and very fine-grained sand. A few calcareous lentils.	
		B 90'	Greenish, reddish and brownish gray varicolored, crumbly, clayey siltstone with a few thin beds of light gray very fine-grained sand.	Trochammina ? sp. Lenticulina theta? Dentalina jacksonensis Bulimina curtissima Pleurostomella? sp. Ellipsonodosaria sp. B. Ellipsonodosaria sp. C. Eponides cf patelliformis
		C 80'	Thinly bedded, brown, silty shale and fine- and very fine-grained sand.	
		D 85'	Light gray, friable, rather thickly-bedded sand, especially in center grading to thinly-bedded brown shale and fine sand above and below.	
Upper Eocene		E 120'	Brown and nearly black, silty and somewhat crumbly shale with ever present coating of yellow jarosite. A few sandy beds and two thin sandstone dikes.	Radiolaria (Common)
				Pecten interradiatus
		F 40'	Hard, platy, black and brown siliceous shale with three soft white bentonite beds varying from 6"–3" in thickness.	Planularia cf. markleyana Spiroloculina? sp. Plectofrondicularia garzaensis Plectofrondicularia sp. Uvigerina garzaensis Hantkenina cf. dumblei
		G 270'	Brown to dark gray, generally well-bedded silty shale, somewhat crumbly in places but often hard and fissile. Three dolomitic beds 1'-3' in thickness used as markers in lower portion.	
		H 45'	5' Light gray friable fine-grained sandstone. 40' Dark gray thinly-bedded, rather crumbly and soft silty shale and clayey silt.	Uvigerina churchi Marginulina asperuliformis Bifarina nuttalli Dentalina hispido-costata Valvulineria advena Globorotalia cf. aragonensis Anomalina dorri- var. aragonensis Bulimina corrugata Buliminella grata Saccorhiza ramosa Martinottiella cf. petrosa
		I 30'	Light gray, friable fine-grained sand.	
Middle Eocene		J 110'	CANOAS SILTSTONE MEMBER. Greenish gray, soft and crumbly, clayey siltstone with a few thin beds of light gray fine sand.	←
	Avenal Sandstone		Brownish gray, rather thickly-bedded fine-to medium-grained sand. Spiroglyphus reef sandstone. Light gray fine-grained, friable sandstone. (Contains Domengine microfauna in McLure Valley)	Spiroglyphus (?) tejonensis

Garza Creek, it is believed that the Garza Creek area is the most complete of the Kreyenhagen sections of the Reef Ridge area.

The section of the Kreyenhagen on Garza Creek is shown graphically in the accompanying diagram. Ten lithologic units are recognized, lettered A to J in descending order. The lowest, unit J, was referred to in an earlier paper[9] as "the greenish-gray silty shale which conformably overlies the Avenal sandstone in this area." It is here named the Canoas siltstone member of the Kreyenhagen shale, the type locality to be in Garza Creek. It consists of greenish-gray soft, crumbly, clayey siltstone, with a few thin beds of light-gray fine sand, and is 110 feet thick. The better exposure of the Canoas siltstone member is at Garza Creek, but the term "Garza" being already preoccupied[10] for a Cretaceous formation some distance north of Coalinga, another name was necessary.

FAUNAL SUMMARY

The species found in the type area are shown in the accompanying table, and the distribution by lots and members is also shown.

The upper part of the formation contains an arenaceous and calcareous foraminiferal fauna. This fauna is distinct from the other Tertiary faunas found in brown shale beds underlying the Miocene sandstones north of Coalinga, in the Devils Den region, and elsewhere, which are characterized by the so-called "*Uvigerina cocoaensis*" fauna. This and the facts that the shales are much thicker north of Coalinga and the *Uvigerina* fauna is found only in their upper part have led Atwill,[11] Goudkoff,[12] and others to assume that the type Kreyenhagen is older than the beds that contain the so-called "*Uvigerina cocoaensis*" fauna or the Tumey formation of Atwill, which also contains that fauna. It is the suggestion of the junior author, however, that the upper beds of the type area are the time equivalent of at least part of the section elsewhere characterized by the "*Uvigerina cocoaensis*" fauna, and that the difference in fauna may be due to differences in ecology, as inferred from the differences in lithology.

9Cushman, J. A., and Siegfus, S. S., New species of Foraminifera from the Kreyenhagen shale of Fresno County, Calif.: Cushman Lab. Foram. Research Contr., vol. 11, p. 91, 1935.

10Huey, A. S., Stratigraphy of the Tesla quadrangle, Calif. [abstract]: Geol. Soc. America Proc., 1936, Cordilleran Section, p. 335, 1937.

11Atwill, E. R., Oligocene Tumey formation of California: Am. Assoc. Petroleum Geologists Bull., vol. 19, no. 8, pp. 1192-1204, 1935.

12Goudkoff, P. P., Subsurface stratigraphy of Kettleman Hills oil field, California: Am. Assoc. Petroleum Geologists, Bull., vol. 18, no. 4, pp. 435-475, 1934.

The lower part of the Kreyenhagen shale is characterized by the so-called Markley fauna of Church[13] and the Canoas siltstone fauna described in this paper. The persistence of these faunas north and south of Coalinga leaves little doubt about the correlation of the lower part of the formation. The Canoas siltstone member, though it contains a somewhat different foraminiferal fauna from the overlying beds, is included in the Kreyenhagen shale because of its shaly composition, a feature distinguishing it from the underlying Avenal sandstone, which contains very little shale.

The subsurface equivalent of the Canoas siltstone member in the Coalinga and Kettleman Hills area appears to be the so-called "novaculite beds" of Barbat.[14] Because of the preponderance of interbedded coarse sand in this part of the section and in view of the notable difference in fauna, it has been suggested that the Canoas siltstone member should be grouped with the Avenal or Domengine sandstone. Referring back to the outcrops in the vicinities of the type localities of the Kreyenhagen, Avenal, and Domengine formations both north and south of Coalinga, where very little sand is present in the Canoas siltstone, it was evident that it was more closely associated with the Kreyenhagen.

COMPARISON OF THE CANOAS CREEK AND GARZA CREEK SECTIONS

The shale exposure close to the old Kreyenhagen No. 1 well in Canoas Creek, which was probably the most important exposure of those found by Anderson south of Coalinga, corresponds with the "E" member of the Garza Creek section (see Plate 14). This part of the Canoas Creek section contains abundant diatoms, radiolarians, and silicoflagellates.[15] Only on one side of this exposure were any Foraminifera found, and these are confined to a small thickness of beds of hard, platy, black, white-weathering shale that correspond to the upper part of the "F" member of the Garza section. The "F" member here, as elsewhere, also contains at least two comparatively thin beds of bentonitic material up to 2 feet in thickness. Overlying the radiolarian beds a short distance

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[13]Church, C. C., Foraminifera of the Kreyenhagen shale: Mining in California, vol. 27, no. 2, pp. 202-213, 1931. More recent work reported on by Boris Laiming (see "Some Foraminiferal Correlations in the Eocene of the San Joaquin Valley, California," Proceedings of the Sixth Pacific Science Congress, Geophysics and Geology, pp. 537-568, 1939, and abstract of the same paper in Bulletin of American Association of Petroleum Geologists, vol. 24, no. 11, pp. 1923-1939, 1940) would place this fauna more specifically in the *Uvigerina churchi* (A-2) zone of Laiming.

[14]Personal communication.

[15]Hanna, G. D., Diatoms and silicoflagellates of the Kreyenhagen shale: Mining in California, vol. 27, no. 2, pp. 187-191, 1931.

down the canyon are beds of white interbedded fine sand that finally grade to a bed some 15 feet in thickness. The top of this sandy zone is not seen along Canoas Creek owing to overburden, but pits indicate that the zone compares favorably in thickness with the "D" member of Garza Creek, which can be traced for some distance. The beds above this sandy zone are better exposed in a small gulley about a quarter of a mile south of Canoas Creek, where with some removal of overburden it was satisfactorily studied. From the sandy "D" member to the top of the formation in the Canoas Creek locality the rock is a brownish gray sandy shale with some interbedded fine gray sand. The shale contains numerous scattered fish remains but no Foraminifera. The whole sequence above the "D" sandy member corresponds rather closely with the "A" and "C" members of the Garza Creek section. The equivalent of the "B" member of the Garza Creek section, consisting of variegated foraminiferal silty shales, could not be found in the Canoas Creek locality. It was later assumed that this zone did not extend beyond the divides of Garza Creek Canyon. This is the only notable difference in the sections of the two localities, but since the total thickness is about the same and the lithology so similar above and below the "D" member, it is believed that the upper limits are roughly contemporaneous. In both areas the top of the formation is marked by a thin bed of small pebbles that indicate a change in lithology to what is considered to be lower Miocene(?) sand. The unconformity is more noticeable at a few places in Garza Creek but is found only with difficulty in Canoas Creek.

Most of the beds below the outcrop near the old Kreyenhagen well, previously described, belong to the "G" member of the Garza Creek section. This is by far the thickest member of the formation and includes all of the shale down to the first sand ("H") member near the base of the formation. The "H" and "I" members immediately below the "G" member are very difficult to find in the Canoas Creek area. Because of excessive overburden that prevents detection, there is even some doubt whether they really are present. The Canoas siltstone member at the base of the formation, however, is recognized at a few places along the outcrop in Canoas Creek because of its distinctive color and proximity to the more resistant Avenal sands. The "H" and "I" members and the Canoas ("J") siltstone member are well exposed on the north side of Garza Creek. There appears to be no unconformity between the Canoas siltstone member and the underlying Avenal sandstone formation, which is rather thinly bedded at the top at most places along Reef Ridge.

The Canoas siltstone contains a rather distinctive foraminiferal fauna characterized by such species as *Marginulina asperuliformis* (Nuttall), *Bifarina nuttalli* Cushman and Siegfus, and *Anomalina dorri* Cole var. *aragonensis* Nuttall. The green color and the fine silty composition of this member are features that aid in its recognition over a rather wide area. In a paper given by the junior author before the Society of Economic Paleontologists and Mineralogists in Los Angeles in May, 1936, this fauna was referred to as the "*Marginulina fragaria* var. *texasensis* fauna" because of the characteristic species, now classified as *Marginulina asperuliformis* (Nuttall).

Comparison North and South of Coalinga

The Kreyenhagen shale was classified as Eocene by F. M. Anderson.[16] Arnold and Anderson,[17] who followed him several years later, also classified the formation as Eocene although they did not accept the formational name. Von Estorff[18] pointed out some similarities to the Eocene elsewhere but was indefinite as to age for the formation. Because the Kreyenhagen shale in many places underlies Miocene sandstones without any striking hiatus, later workers raised the question of its being Oligocene in age, at least in part. In 1935, Atwill[19] showed that the upper part of what had been formerly referred to as Kreyenhagen shale north of Coalinga contained Oligocene fossils. For the upper part of the section that in the area north of Coalinga included most of the occurrences of "*Uvigerina cocoaensis*" he proposed the term "Tumey formation." Because the type Kreyenhagen shale south of Coalinga, referred to as "Kreyenhagen" by Atwill, was not believed to include any correlative of the Tumey formation he believed the term "Tumey formation" justified, although the term "Wagon Wheel formation"[20] had been proposed some years earlier for beds occupying a similar position in the geologic column.

16Anderson, F. M., A stratigraphic study of the Mount Diablo Range of California: California Acad. Sci., Proc., 3d ser., Geology, vol. 2, no. 2, p. 163, 1905.

17Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, pp. 58-70, 1910.

18Von Estorff, F. E., Kreyenhagen shale at type locality, Fresno County, Calif.: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 1321-1337, 1930.

19Atwill, E. R., Oligocene Tumey formation of California: Am. Assoc. Petroleum Geologists Bull., vol. 19, no. 8, pp. 1192-1204, 1935.

20Johnson, H. R., Geology of the McKittrick-Sunset district, Calif. [abstract]: Science, new ser., vol. 30, pp. 63-64, 1909.

Church[21] showed that the lower part of the Kreyenhagen shale north of Coalinga and elsewhere contained a foraminiferal fauna similar to that of the Markley formation. With the work of Bailey[22] and Clark[23] showing that the Markley formation was rather definitely upper Eocene in age, the age of the lower part of the Kreyenhagen shale appears to be fairly well established.

The question of the age of the upper part of the Kreyenhagen shale has been somewhat more difficult. Evidence from certain wells of the Jacalitos Dome area which indicated that the upper part of the type Kreyenhagen shale might be the equivalent of at least part of the Tumey shale of Atwill or the *"Uvigerina cocoaensis"* zone was presented by the junior author at the Los Angeles meeting of the Society of Economic Paleontologists and Mineralogists in May, 1936. In the Superior Oil Company's "Mantes" No. 1 well, in which the total thickness of the Kreyenhagen shale was only 900 feet, the *"Uvigerina cocoaensis"* fauna was found less than 500 feet above the base. This well is only 5 miles north, but basinward, from the type locality. The same fauna was found in the upper 100 feet of the Kreyenhagen shale in the Associated's "Mitchell" No. 1 well, a few miles northwest of the "Mantes" well, where the total thickness of this shale was only about 400 feet.

Almost everywhere in the San Joaquin Valley the *"Uvigerina cocoaensis"* fauna is found in a peculiar clayey rock of brown, brownish-gray, or gray color. The upper part of the formation in the Reef Ridge type area is more sandy than the upper part of the formation in other areas. The "B" member with its lithology of mottled pink and green is strongly suggestive of deposition in appreciably shallower water than any indicated by the features of the *"Uvigerina cocoaensis"* beds. The lack of Foraminifera in the "A" and "C" members, along with the large proportion of interbedded sand, indicates that shallow water and an oscillating shore line were the conditions in the type area during much of late Kreyenhagen time. This is in contrast to the deeper water and more constant conditions indicated for the deposition of the *"Uvigerina cocoaensis"* beds.

There are other examples in the area of the effect of ecologic

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[21]Church, C. C., Foraminifera of the Kreyenhagen shale: Mining in California, vol. 27, no. 2, pp. 202-213, 1931.

[22]Bailey, T. L., The geology of the Potrero Hills and Vacaville region, Solano County, Calif.: California Univ., Dept. Geol. Sci., Bull., vol. 19, no. 15, pp. 321-333, 1930.

[23]Clark, B. L., Fauna from the Markley formation (upper Eocene) on Pleasant Creek, Calif.: Geol. Soc. America Bull., vol. 49, no. 5, pp .683-730, 1938.

differences in beds of this character. In the Texas Company's "Circle" No. 1 well, in the Coalinga area, greenish clay-shales were found to be interbedded with brown silty shales. The greenish clay-shales contained the *Marginulina asperuliformis* foraminiferal fauna characteristic of the Canoas siltstone member, whereas the brown shales contained the Markley fauna of Church.

A short distance north of Little Tar Canyon, the Knudson & Schmidt No. 1 well, drilled by the Pacific Western Oil Corporation, encountered the "*Uvigerina cocoaensis*" fauna in the upper part of the shale underlying the Miocene Temblor sandstone. The upper part of the Kreyenhagen shale at the outcrop, about three-quarters of a mile west, contains no Foraminifera, as far as could be determined, and is similar to the "E" and "F" members of the type area. The well reached a sandy zone below the "*Uvigerina cocoaensis*" occurrences that is believed to be the equivalent of the "D" member at the outcrop to the west, thus indicating that the barren overlying "A" and "C" members of the type area are the equivalents of the "*Uvigerina cocoaensis*" beds encountered in the well. In this area the "D" member is the only sandy horizon known in this part of the Kreyenhagen sequence.

In Phoenix Canyon, north of Coalinga, the white "punky" beds that are the equivalents of the "*Uvigerina cocoaensis*" zone are seen to underlie disconformably the Miocene sandstone. The shale underlying the "*Uvigerina cocoaensis*" zone is also disconformable.[24] The 100 feet of shale below the unconformity marking the base of the "*Uvigerina cocoaensis*" zone contains abundant radiolarians and is classified as the equivalent of the "E" member of the type area south of Coalinga. Under this member is found a hard platy shale unit carrying *Spiroloculina?* and two bentonitic beds comparable to the "F" member of Garza Creek. Below some 40 to 50 feet of this type of shale the formation was seen to be practically identical in lithology and fauna to the "G" member of the Reef Ridge area. The Canoas silt member and zones below the "G" member are not present in Phoenix Canyon proper but occur a short distance north at hill 2126, from which Foraminifera were described by Cushman and Hanna.[25]

From these evidences it is believed likely that the upper part of the Kreyenhagen shale of the type area, the part of the formation down to

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[24]Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, Calif.: U. S. Geol. Survey Bull. 398, 1910. See photograph opposite p. 162.

[25]Cushman, J. A., and Hanna, G. D., Foraminifera from the Eocene near Coalinga, Calif.: California Acad. Sci., Proc., 4th ser., vol. 16, no. 8, pp. 205-228, 1927.

the base of the "D" sandy member, is the equivalent in part, at least, of the Tumey formation of Atwill or "*Uvigerina cocoaensis*" zone. From Atwill's paper[26] this part of the formation would appear to be Oligocene. From our comparison of the species found in the "B" member at Garza Creek this part of the section would be related to the upper Eocene of Mexico and the Gulf Coast. However, until such time as Effinger's Gaviota stage and the Eocene-Oligocene contact in California are more clearly defined, it does not appear likely that the uppermost part of the type Kreyenhagen can be definitely classified as to age. Following W. L. Effinger's latest known usage,[27] most of the Kreyenhagen would be classed as upper Eocene or Jackson in age, possibly extending down into the upper Claiborne or Auversian of the European classification.

California Age Relationships

In the recent publication on the Eocene by B. L. Clark and H. E. Vokes,[28] the Eocene is divided into seven stages, the upper four being the Gaviota, Tejon, Transition, and Domengine, in descending order. The Avenal sandstone is placed by these authors in the Domengine stage, and the Kreyenhagen shale is considered equivalent to the Gaviota and the Tejon stages, and possibly to the upper part of the Transition stage. The Kreyenhagen shale in this paper is used in the broad sense to include both the Tumey formation of Atwill and the type Kreyenhagen shale, so that the point of most concern to micro-paleontologists is not discussed except to note that the upper part (Tumey) is considered Oligocene in age and therefore the Gaviota stage may be partly Oligocene in age.

As pointed out previously, the lower part of the Kreyenhagen shale which contains the Markley microfauna has been rather definitely classified as belonging to the Tejon stage and is comparable with the upper part of the Tejon Eocene as described by early authors. This classification applies to the lower part of the Kreyenhagen shale quite generally. The Canoas siltstone member, which underlies the Markley microfaunal zone, may well correspond to Clark's Transition stage, since the Avenal sandstone is classified as of the Domengine stage. The

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[26]Atwill, E. R., Oligocene Tumey formation of California: Am. Assoc. Petroleum Geologists Bull., vol. 19, no. 8, pp. 1192-1204, 1935.

[27]Effinger, W. L., Gaviota formation of Santa Barbara County [abstract]: Pan-Am. Geologist, vol. 64, no. 1, p. 75, 1935.

[28]Clark, B. L., and Vokes, H. E., Summary of marine Eocene sequence of western North America: Geol. Soc. America Bull., vol. 47, no. 6, pp. 851-878, 1936.

Canoas siltstone foraminiferal fauna, characterized by species found in the Claiborne and older formations, would appear to support this view.

The upper part of the Eocene and younger beds had been subdivided into stages on the basis of Foraminifera by Schenck and Kleinpell[29] a short time prior to Clark and Vokes' paper. In this paper the *Turritella variata* zone of Woodring,[30] including the so-called Tumey formation, was classified as the Refugian stage. Their unnamed stage below the Refugian would be essentially the same as Clark and Vokes' Tejon stage. Under this are listed the Foraminifera most common in Church's Markley fauna, including *Planularia markleyana* Church, *Plectofrondicularia jenkinsi* Church, and *Robulus welchi* Church. *Discocyclina clarki* (Cushman) and *Marginulina mexicana* Cushman are also mentioned, but in the areas along the west side of the San Joaquin Valley studied by the junior author, *Discocyclina* cf. *D. clarki* (Cushman) and *Marginulina mexicana* subsp. *nudicostata* (Cushman and G. D. Hanna) were assigned to Domengine and the Avenal sandstone. The Refugian stage is considered by its authors to be probably equivalent in age to a portion of the upper Eocene or lower Oligocene series of Europe.

GENERAL AGE RELATIONSHIPS

Comparison of the foraminiferal species here described with those from other parts of the world indicates a rather close similarity to the other known Eocene faunas. The lower part of the formation contains certain species known only from the Eocene Aragon formation of Mexico. A little higher in the section are species known from the Guayabal formation of Mexico and the Claiborne group of the Coastal Plain region of the United States. The upper part of the section contains species that are identical with those known from the Chapapote formation of Mexico, which is considered to be of upper Eocene or Jackson age.

CONCLUSIONS

The following conclusions have been drawn regarding the type Kreyenhagen shale:

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[29]Schenck, H. G., and Kleinpell, R. M., Refugian stage of Pacific coast Tertiary: Am. Assoc. Petroleum Geologists Bull., vol. 20, no. 2, pp. 215-225, 1936.

[30]Woodring, W. P., Upper Eocene oribitoid Foraminifera from the western Santa Ynez Range, Calif., and their stratigraphic significance: San Diego Soc. Nat. History Trans., vol. 6, no. 4, p. 160, 1930.

1. F. M. Anderson, in the original definition of the typical Kreyenhagen shale at the Canoas Creek locality, did not indicate a definite top and base for the formation. The rather inconspicuous unconformity at the top of the Kreyenhagen shale and the base of the Canoas siltstone member at the bottom are here taken as the limits of the formation, the lower contact being conformable with the Avenal sandstone and at places somewhat gradational.

2. The Kreyenhagen shale is much better exposed at Garza Creek than in the originally specified area on Canoas Creek. Because of the proximity of the two areas and the fact that the uppermost and lowermost members in each locality are more or less identical, the Garza Creek area is suggested as supplemental to the type locality. The Garza Creek section also contains the foraminiferal zone in the "B" member, which is either very poorly developed or lacking at Canoas Creek. Both localities together are considered in this paper as the type area.

3. The lower part of the Kreyenhagen is as old as the Claiborne of the Gulf Coast area. The upper part is mostly not younger than Jackson in age. The Gaviota stage, as recognized by Clark and Vokes, is not clearly defined with respect to the Eocene-Oligocene contact and future work may show that a part of the Kreyenhagen is Oligocene in age.

4. The formation is characterized essentially by three foraminiferal faunules:

(1) The upper Kreyenhagen, or "B" member, faunule, characterized by the following:

Bulimina curtissima Cushman and Siegfus
Dentalina jacksonensis (Cushman and Applin)
Ellipsonodosaria sp.
Lagena acuticosta Reuss

(2) The lower Kreyenhagen faunule, or Markley fauna of Church. Characteristic species in the lower Kreyenhagen above the Canoas siltstone member are:

Hantkenina dumblei Weinzierl and Applin
Plectofrondicularia garzaensis Cushman and Siegfus
Planularia markleyana Church
Pullenia eocenica Cushman and Siegfus
Spiroloculina? sp.
Uvigerina churchi Cushman and Siegfus

(3) The Canoas siltstone faunule, or *Marginulina asperuliformis* zone, with:

Marginulina asperuliformis (Nuttall)
Bifarina nuttalli Cushman and Siegfus
Dentalina hispido-costata Cushman and Siegfus
Valvulineria advena Cushman and Siegfus
Globorotalia aragonensis Nuttall
Anomalina dorri Cole var. aragonensis Nuttall
Bulimina corrugata Cushman and Siegfus
Buliminella grata Parker and Bermúdez
Saccorhiza ramosa (H. B. Brady)
Martinottiella cf. M. petrosa (Cushman and Bermúdez)

5. The upper part of the type Kreyenhagen shale down to the base of the sandy "D" member is considered by the junior author to be the equivalent in part at least of the Tumey formation of Atwill and the "*Uvigerina cocoaensis*" beds.

NOTES ON THE SPECIES

FAMILY RHIZAMMINIDAE

Genus **Bathysiphon** G. O. Sars, 1871

Bathysiphon eocenica Cushman and G. D. Hanna

Plate 15, figure 1

Bathysiphon eocenica CUSHMAN and G. D. HANNA, Proc. Calif. Acad. Sci., ser. 4, vol. 16, No. 8, p. 210, pl. 13, figs. 2, 3, 1927.—Cushman and McMasters, Jour. Paleontology, vol. 10, p. 508, pl. 74, fig. 1, 1936.

This species already recorded from the Eocene, 7 miles north of Coalinga and from the Llajas formation of Ventura County, California, occurs in the Garza Creek and Canoas Creek sections. As usual, only short broken pieces of the test are found. In general shape and size they agree well with those from the other localities.

FAMILY HYPERAMMINIDAE

Genus **Hyperammina** H. B. Brady, 1878

Hyperammina elongata H. B. Brady ?

Plate 15, figures 2, 3

There are scattered fragments from a number of levels in the Garza Creek section which may be referred to Brady's species with some question. The diameter is rather uniform although a few of them show slight constrictions as in our figure.

Genus **Saccorhiza** Eimer and Fickert, 1899

Saccorhiza ramosa (H. B. Brady) ?

A few short fragments strongly resembling this species occur in the Garza Creek section. None of these show a distinct branching but have the peculiar twisted shape of Brady's species.

Family AMMODISCIDAE

Ammodiscus sp.

Plate 15, figure 4

A very few rather poorly preserved specimens occur in the lower portion of the section. They resemble specimens from the Eocene Chapapote of Mexico.

Family LITUOLIDAE

Genus **Cyclammina** H. B. Brady, 1876

Cyclammina samanica W. Berry

Plate 15, figure 5

Cyclammina samanica W. Berry, Ecliogae Geologicae Helvetiae, vol. 21, p. 393, text fig. 5a, b, 1928.

Haplophragmoides acuticostatum Nuttall (Not Hantken), Jour. Paleontology, vol. 4, p. 279, pl. 23, figs. 2, 3, 1930.

Specimens referable to this species occur in both the Garza Creek and Canoas Creek sections. They are apparently identical with the species described by Berry from the Eocene Lobitos shales of Northwestern Peru. The test is slightly depressed in the center and again toward the periphery which is rounded and almost suggests a broad keel. There are eight to ten chambers in the final coil often of somewhat irregular size.

Nuttall figures specimens from the Eocene Aragón formation of Mexico that, on examination are seen to be the same as ours, but they are not the same as topotypes of Hantken's species, which is much larger.

Family TEXTULARIIDAE

Genus **Textularia** Defrance, 1824

Textularia mississippiensis Cushman

Plate 15, figure 6

This species which is characteristic of the upper Eocene and lower Oligocene of the Gulf Coastal Plain region of the United States is rare in the Kreyenhagen but the figured specimen is typical.

Genus **Vulvulina** d'Orbigny, 1826

Vulvulina curta Cushman and Siegfus

Plate 15, figures 7, 8

Vulvulina curta Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 11, p. 91, pl. 14, figs. 1, 2, 1935.

"Test nearly as broad as long, compressed, periphery acute, spinose in the biserial portion; chambers rather indistinct, earliest ones planispiral, later biserial ones low and broad, of rather uniform height, the peripheral portion ending in a short, pointed spine, uniserial chambers only one or two, much narrower than the preceding portions of the test; sutures mostly indistinct except in the uniserial portion where they are distinctly depressed; wall finely arenaceous, mostly smooth; aperture in the uniserial portion elongate, elliptical, terminal. Length 0.60 mm.; breadth 0.50 mm."

The relationships of this species are with those of the Mexican Eocene. It somewhat resembles *V. colei* Cushman from the Chapapote formation of Mexico although the uniserial chambers of that species are more developed than in the California one. In the Garza Creek section *V. curta* occurs at a number of different levels.

FAMILY VERNEUILINIDAE

Genus **Clavulinoides** Cushman, 1936

Clavulinoides sp.

Plate 19, figures 1-3

There are a very few specimens from two localities that evidently belong to this genus but not enough for a complete description of the species. While not identical, they most closely resemble *Clavulinoides cubensis* Cushman and Bermúdez and *C. marielinus* Cushman and Bermúdez described from the Eocene of Cuba.

FAMILY VALVULINIDAE

Genus **Dorothia** Plummer, 1931

Dorothia principensis Cushman and Bermúdez

Plate 15, figure 9

Dorothia principensis CUSHMAN and BERMUDEZ, Cushman Lab. Foram. Research Contr., vol. 12, p. 57, pl. 10, figs. 3, 4, 1936.—Cushman, loc. cit., Special Publ. 8, p. 87, pl. 9, figs. 20, 21, 1937.—Bermúdez, Soc. cubana historia nat. Mem., vol. 12, p. 4, 1938.—Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 24, pl. 6, fig. 23, 1939.

"Test small, elongate, about two and one-half times as long as broad, very slightly compressed, biserial portion making up nearly the entire test, periphery lobulate; chambers distinct except in the earliest portion, of rather uniform size throughout, becoming slightly more inflated toward the apertural end; sutures distinct, depressed in the biserial portion nearly at right angles to the vertical axis; wall finely arenaceous, smoothly finished; aperture a low, arched opening at the inner margin of the last-formed chamber. Length 0.80 mm.; diameter 0.30 mm."

This species was originally described from the Eocene lower Principe formation of Cuba. It is one of the species which connects this Garza Creek Eocene with that of Cuba.

Dorothia ? sp.

Plate 19, figures 4-6

The specimens figured may belong to this genus although the structure of the early chambers is obscure or missing. They do not seem identical with any described species.

Genus **Plectina** Marsson, 1878

Plectina garzaensis Cushman and Siegfus

Plate 15, figures 10, 11

Plectina garzaensis Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 11, p. 92, pl. 14, figs. 3, 4, 1935.—Cushman, loc. cit., Special Publ. 8, p. 109, pl. 12, figs. 18-20, 1937.

"Test elongate, subcylindrical or slightly tapering from the greatest breadth near the apertural end, somewhat nodose, nearly circular in transverse section, earliest whorl with more than three chambers, then triserial, biserial in the adult or tending to become uniserial; chambers of the early portion indistinct, later ones somewhat inflated, increasing in height as added; sutures indistinct in the early stages, later more distinct and depressed; wall coarsely arenaceous, somewhat roughly finished; aperture in the adult nearly terminal, rounded, without a neck. Length up to 0.90 mm.; diameter 0.30 to 0.40 mm."

The types of this species are from our Garza Creek section where it is fairly common and has a rather wide vertical range. It is closely related to *P. elongata* Cushman and Bermúdez from the Eocene lower Principe formation of Cuba.

Genus **Martinottiella** Cushman, 1933

Martinottiella cf. **M. petrosa** (Cushman and Bermúdez)

Plate 15, figure 14

A very few specimens closely resembling shorter forms of this species described from the Eocene of Cuba occur in the basal part of the Kreyenhagen section. They also resemble specimens from the Chapapote of Mexico referred by Cole to "*Clavulina communis* d'Orbigny."

Genus **Tritaxilina** Cushman, 1911

Tritaxilina colei Cushman and Siegfus

Plate 15, figures 12, 13

Tritaxilina colei Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 11, p. 92, pl. 14, figs. 5, 6, 1935.—Cushman, loc. cit., Special Publ. 8, p. 155, pl. 18, figs. 1-3, 1937.—Bermúdez, Soc. cubana historia nat. Mem., vol. 12, p. 24, 1938.

"Test one and one-half to two times as long as broad, somewhat tapering at the base, and having its greatest breadth near the middle, the adult again tapering somewhat toward the apertural end, rounded in transverse section; chambers in the early portion with more than three to a whorl, having a distinct, four-chambered stage, after which triserial and then biserial chambers are developed; sutures distinct, slightly depressed; wall rather coarsely arenaceous, the basal portion of each chamber somewhat raised; aperture nearly terminal in the adult, and the whole test tending to become somewhat uniserial at that stage. Length 0.60 to 0.75 mm.; diameter 0.30 mm."

The types are from the Eocene Chapapote formation, Chapapote, Mexico. It occurs in typical form in our Garza Creek material.

Family MILIOLIDAE

Genus **Spiroloculina** d'Orbigny, 1826

Spiroloculina ? sp.

Plate 15, figures 15-17

A few specimens seem to belong to *Spiroloculina,* but the specimens are not well preserved. Some resemble in general appearance *Massilina decorata* Cushman of the Eocene of the Coastal Plain region but the California specimens appear to be planispiral throughout.

Genus **Sigmoilina** Schlumberger, 1887

Sigmoilina ? sp.

Plate 15, figure 18

A very few specimens of an arenaceous form may belong to this genus. They are not well enough preserved to show the structure fully.

Family TROCHAMMINIDAE

Genus **Trochammina** Parker and Jones, 1859

Trochammina sp.

There are a few scattered specimens of *Trochammina* which are much distorted and not to be specifically determined until more and better material is available.

Family LAGENIDAE

Genus **Robulus** Montfort, 1808

Robulus alato-limbatus (Gümbel)?

Plate 15, figures 19-21

There are a number of specimens, some not well preserved, which resemble this rather widely distributed species. The three specimens figured show some of the variations in our material. Some of the specimens resemble the figure given by Cole of Mexican Eocene material referred by him to *Robulus articulatus* (Reuss).

Robulus pseudovortex Cole

Plate 15, figure 23

Robulus pseudovortex Cole, Bull. Am. Paleontology, vol. 14, no. 51, p. 19, pl. 1, fig. 12, 1927.—Cushman and McMasters, Jour. Paleontology, vol. 10, p. 510, pl. 74, figs. 12a, b, 1936.

Cole originally described this species from the Eocene Guayabal formation of Mexico, and it has also been recorded from the middle Eocene Llajas formation of Ventura County, California. The specimens from the Garza Creek section are very close to these others.

Robulus welchi Church ?

Plate 15, figure 22

The figure given by Church of this species (Mining in California, vol. 27, pl. C, figs. 13, 14, 1931) from the upper Eocene of California is in some of its characters close to the specimen we have figured here from the Garza Creek material. More specimens are necessary before this determination can be assured. Our specimen also closely resembles the species, *Robulus terryi* Coryell and Embich, recently described from the upper Eocene of Panama.

Robulus gyroscalprus (Stache)?

Plate 15, figure 24

The specimen figured in some respects resembles Stache's species from the Eocene of New Zealand. It also has some characters that suggest *R. pseudovortex* Cole. More material must be obtained for a study of the variation of this species.

Robulus sp.

Plate 15, figure 25

A number of specimens of a species with longitudinal costae may represent young stages of some larger form. It is figured here for the record.

Genus **Lenticulina** Lamarck, 1804

Lenticulina theta Cole ?

Plate 15, figure 26

The single specimen here figured resembles that figured and described by Cole (Bull. Am. Paleontology, vol. 14, no. 51, p. 14, pl. 1, fig. 17, 1927) from the Eocene Guayabal formation of Mexico.

Genus **Dentalina** d'Orbigny, 1826

A number of species may be referred to this genus tentatively that are represented in our material by such fragmentary specimens that it is difficult to assign names to them with any degree of certainty. Notes are given suggesting their stratigraphic relations which seem to be mainly with the Eocene of Mexico and Trinidad. It may be that the relationships of these species are with the Ellipsoidinidae but that can only be determined when their apertural characters are fully known.

Dentalina ? sp.

Plate 16, figures 1, 2

The figures given show curved specimens with rather uniform chambers but the apertural end is broken so that no apertural characters are present. The two figures are generally much alike, each with basal spine but the sutures in one are rather more depressed than in the other.

Dentalina ? sp.

Plate 16, figures 3, 4

The two fragmentary figures given are somewhat similar to those given by Cole (Bull. Am. Paleontology, vol. 14, no. 51, p. 21, pl. 3, figs. 10, 11, 1927) from the Eocene Guayabal formation of Mexico as "*Vaginulina legumen* (Linné), var. *elegans* d'Orbigny."

Dentalina ? sp.

Plate 16, figure 5

This fragmentary specimen is sufficiently well characterized so that its identity with the specimen figured by Cole (loc. cit., p. 17, pl. 3, fig. 17) from the Eocene Guayabal of Mexico is rather clearly suggested. It also resembles specimens figured by Nuttall from the Eocene of Trinidad (Quart. Jour. Geol. Soc., vol. 84, p. 81, pl. IV, figs. 9, 10, 1928) as "*Nodosaria knihnitziana* Karrer." This probably is an *Ellipsonodosaria.*

Dentalina ? sp.

Plate 16, figure 6

Nodosaria sp., Cole, Bull. Am. Paleontology, vol. 14, no. 51, p. 17, pl. 1, fig. 21, 1927.

Our specimen seems to be identical with that figured by Cole from the Eocene Guayabal of Mexico. Our specimen shows the complete initial end while Cole's specimen shows more of the adult chambers.

Dentalina ? sp.

Plate 16, figure 8

Fragmentary specimens occur which show the early portion nearly smooth and later chambers with a row of spines near the base. None of the specimens show the apertural characters and the species may belong to *Ellipsonodosaria.* These fragments suggest the form recorded from the upper Eocene Cooper marl of South Carolina as *Dentalina* cf. *D. adolphina* d'Orbigny (Cushman, U. S. Geol. Survey Prof. Paper 181, p. 21, pl. 8, fig. 11, 1935). Under this same name Cushman and G. D. Hanna have recorded somewhat similar specimens from the upper Eocene of California (Proc. Calif. Acad. Sci., ser. 4, vol. 16, p. 213, pl. 13, figs. 8, 9, 1927). In some respects it suggests "*Nodosaria olinata* Cole" from the Eocene Guayabal formation of Mexico (Bull. Am. Paleontology, vol. 14, no. 53, p. 16, pl. 3, fig. 16, 1927).

Dentalina ? sp.

Plate 16, figure 9

The single specimen figured differs from the preceding in the double row of shorter spines and the more definitely separated chambers. It suggests the form referred to "*Nodosaria aculeata* d'Orbigny" from the upper Eocene of Mexico (Cushman, Jour. Paleontology, vol. 1, p. 154, pl. 24, fig. 4, 1927).

Dentalina ? sp.

Plate 16, figures 10, 11

The figured specimens, though but fragments, give a fairly good idea of the ornamentation of this species. It is somewhat similar to the form figured as "*Dentalina* cf. *D. adolphina* d'Orbigny" from the Eocene Cooper marl of South Carolina (Cushman, U. S. Geol. Survey Prof. Paper 181, p. 21, pl. 8, fig. 12, 1935). It may belong to *Ellipsonodosaria* but the apertural characters are lacking in our specimens.

Dentalina jacksonensis (Cushman and Applin)
Plate 16, figure 7

Nodosaria jacksonensis CUSHMAN and APPLIN, Am. Assoc. Petroleum Geologists Bull., vol. 10, p. 170, pl. 7, figs. 14-16, 1926.—Cushman, Jour. Paleontology, vol. 1, p. 153, pl. 24, fig. 3, 1927.—Cole, Bull. Am. Paleontology, vol. 14, no. 53, p. 208, pl. 3, fig. 12, 1927.

Dentalina jacksonensis CUSHMAN, U. S. Geol. Survey Prof. Paper 181, p. 20, pl. 8, figs. 7-9, 1935.—Cushman and McMasters, Jour. Paleontology, vol. 10, p. 511, pl. 75, figs. 3-5, 1936.—Coryell and Embich, Jour. Paleontology, vol. 11, p. 298, pl. 42, fig. 8, 1937.

The fragment figured shows chambers toward the apertural end, which are very similar to this species characteristic of the upper Eocene of the Gulf Coastal Plain of the United States and of Mexico. The form figured by Nuttall from the upper Eocene of Trinidad as "*Nodosaria crassielegans*" (Quart. Jour. Geol. Soc., vol. 84, p. 80, pl. 4, figs. 6, 7, 1928) is close to *D. jacksonensis.*

Dentalina hispido-costata Cushman and Siegfus
Plate 16, figures 12, 13

Dentalina hispido-costata CUSHMAN and SIEGFUS, Cushman Lab. Foram. Research Contr., vol. 15, p. 25, pl. 6, figs. 4, 5, 1939.

"Test elongate, uniserial, of nearly uniform diameter throughout; chambers subglobular, of almost equal size, proloculum as large as the succeeding chambers, earlier ones much overlapping, later ones with distinct contractions over the sutures and more separated; sutures distinct, slightly depressed in the earliest portion, gradually more so as chambers are added; wall of the proloculum hispid or finely spinose, becoming definitely longitudinally costate in the following chambers, last-formed ones smooth; aperture radiate, with a slightly tapering neck, eccentric. Length up to 1.30 mm.; diameter, 0.20 to 0.30 mm."

The types are from the Eocene Kreyenhagen shale, Oil Canyon, 30 feet above upper sand, near W 1/4 corner, Sec. 16-19-15, California.

This species somewhat resembles *D. halkyardi* Cushman but differs in the parallel sides and the reverse development of the ornamentation which in *D. halkyardi* starts with longitudinal costae and becomes spinose while our species starts with a spinose proloculum and becomes costate.

Genus **Nodosaria** Lamarck, 1812

Nodosaria ? sp.
Plate 16, figure 23

Numerous fragments from the lower part of the section apparently belong to *Nodosaria.* The chambers so far as shown in our specimens are elongate and the surface, especially the area over the sutures, has fine longitudinal costae. No specimens with more than two chambers intact have been found, but fragments are numerous.

Nodosaria ? sp.
Plate 19, figure 12

A single broken specimen of this strongly costate species is figured.

Genus **Planularia** Defrance, 1824

Planularia cf. P. markleyana Church
Plate 16, figures 14-17

A number of specimens, although not very well preserved, seem very close to the above species described from the Eocene of California. There are specimens in a rock matrix which are difficult to figure but show the elongate, uncoiling form typical of this species. It has a very limited vertical range as far as our material shows.

Genus **Marginulina** d'Orbigny, 1826

Marginulina subbullata Hantken
Plate 16, figure 21

Marginulina subbullata Hantken, Magyar kir. földt. int. Evkönyve, 1875, vol. 4, p. 39, pl. 4, figs. 9, 10; pl. 5, fig. 9, 1876.—Liebus, K.-k. geol. Reichsanstalt Jahrb., vol. 56, p. 354, 1906.—Cushman, Cushman Lab. Foram. Research Contr., vol. 1, pt. 3, p. 62, pl. 10, figs. 3a, b, 1925.—Cushman and G. D. Hanna, Proc. Calif. Acad. Sci., ser. 4, vol. 16, p. 216, pl. 13, fig. 11, 1927.—Cole, Bull. Am. Paleontology, vol. 14, no. 51, p. 14, pl. 5, fig. 10, 1927.—Cushman, Cushman Lab. Foram. Research Contr., vol. 5, p. 85, pl. 12, fig. 20, 1929.—Nuttall, Jour. Paleontology, vol. 9, p. 125, p. 14, fig. 16, 1935.—Coryell and Embich, Jour. Paleontology, vol. 11, p. 297, pl. 42, fig. 2, 1937.—Bermúdez, Soc. cubana historia nat. Mem., vol. 12, p. 15, 1938.—Parr, Jour. Roy. Soc. W. Australia, vol. 24, p. 75, pl. 1, fig. 6, 1938.—Cushman, Cushman Lab. Foram. Research Contr., vol. 15, p. 55, pl. 9, figs. 30, 31, 1939.

This species originally described by Hantken from the upper Eocene of Hungary and recorded by Liebus from material of equivalent age from Biarritz, France, has been recorded from several localities in the upper Eocene and lower Oligocene of Venezuela, Mexico, Cuba, and California, as well as from the Georges Banks and Australia. Material from the Wilcox Eocene and specimens from the Miocene have also been referred to it but these do not seem to be typical. Our figured specimen seems to be identical with Hantken's species. It is variable in its early stages.

Marginulina asperuliformis (Nuttall)
Plate 16, figures 18-20

Cristellaria asperuliformis Nuttall, Jour. Paleontology, vol. 4, p. 282, pl. 23, figs. 9, 10, 1930.

Marginulina asperuliformis Bermudez, Soc. cubana historia nat. Mem., vol. 12, p. 15, 1938.—Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 24, pl. 6, figs. 1-3, 1939.

"Test with earlier portion close-coiled, later portion uncoiled, compressed, especially in the earlier portion. Chambers distinct, separated by elevated limbate sutures, which bear fine tubercles that are variable in number and become less pronounced or absent in the last chambers. Aperture radial, terminal. Periphery sharp, in most specimens with a thin narrow keel. Average length 1.5 mm."

This species was described by Nuttall as above from the Eocene Aragón formation of Mexico. He notes that it is practically confined to this formation. It is of interest to compare our specimens with Nuttall's types and to find that they are apparently the same species. There is considerable variation but our specimens show about the same range of variation as do his. This would seem to be a good marker for correlating the lower part of the Kreyenhagen with the Aragón of Mexico.

Marginulina ? sp.

Plate 16, figure 22

The single specimen of this particular form is figured. More material is needed even to be certain of its genus.

Genus **Lagena** Walker and Jacob, 1798

Lagena acuticosta Reuss

Plate 16, figure 24

Lagena acuticosta Reuss, Akad. Wiss. Wien Sitzungsber., vol. 44, pt. 1, p. 305, pl. 1, fig. 4, 1862.—Cushman, U. S. Geol. Survey Prof. Paper 181, p. 23, pl. 9, figs. 5, 6, 1935.

The single specimen figured is similar to this species, which has been recorded from the upper Eocene of the Gulf Coastal Plain region of the United States.

Lagena cf. **L. orbignyana** (Seguenza)

Plate 16, figure 25

Nuttall records this species in his Eocene Aragón material from Mexico. We have a single specimen that resembles his, although it is doubtful if either is the same as Seguenza's species.

Family POLYMORPHINIDAE

Genus **Globulina** d'Orbigny, 1839

Globulina gibba d'Orbigny

Plate 16, figure 26

This widely distributed species, recorded from many localities in the Eocene of the United States and Mexico is the only one of the family appearing in our material.

Family HETEROHELICIDAE

Genus **Bolivinopsis** Yagovlev, 1891

Bolivinopsis directa (Cushman and Siegfus)

Plate 16, figures 27, 28

Spiroplectoides directa Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 26, pl. 6, figs. 7, 8, 1939.

"Test elongate, about three times as long as wide, strongly compressed, periphery acute or slightly keeled, sides nearly parallel, initial end broadly rounded; chambers in the early stages planispiral, later biserial, low and broad in the adult of rather uniform size and shape; sutures distinct, nearly flush with the surface, slightly limbate, curved near the inner end, thence nearly straight and gently sloping to the periphery where they merge with the slight keel; wall calcareous, fairly thin, coarsely perforate; aperture elongate, terminal. Length 0.60 to 0.75 mm.; diameter 0.20 mm."

The types are from the Kreyenhagen shale, upper Garza Creek, California, 104 feet below the top of the Kreyenhagen.

This species differs from *S. curta* Cushman in the more reduced spiral portion, greater compression of the test, and the larger number of chambers which are also much lower and broader.

Genus **Plectofrondicularia** Liebus, 1903

Plectofrondicularia garzaensis Cushman and Siegfus

Plate 16, figure 29

Plectofrondicularia garzaensis CUSHMAN and SIEGFUS, Cushman Lab. Foram. Research Contr., vol. 15, p. 26, pl. 6, fig. 9, 1939.

"Test oval or broadly elliptical in front view, very strongly compressed, sides flattened, periphery with a narrow thin keel except toward the apertural end; chambers numerous, only the very earliest ones showing the biserial arrangement, later ones chevron-shaped, increasing rather rapidly but regularly in size and height as added; sutures very distinct, gently curved, slightly limbate, very slightly if at all depressed; wall smooth, very finely perforate. Length 0.75 to 1.00 mm.; breadth 0.60 to 0.70 mm."

The types are from Kreyenhagen shale, Garza Creek, California, 104 feet below the top of the Kreyenhagen.

This species differs from *P. vaughani* (Cushman), which it most closely resembles, in the more broadly elliptical form, more rounded initial end, more definite keel and fewer biserial chambers.

Plectofrondicularia sp.

Plate 16, figure 30

The specimen figured in some respects resembles *P. packardi* Schenck and Cushman (Univ. Calif. Publ. Bull. Dept. Geol. Sci., vol. 17, p. 311, pl. 43, figs. 14, 15, 1928) in the costae of the early portion. Not enough specimens are available to warrant a full description of the species.

Genus **Amphimorphina** Neugeboren, 1850

Amphimorphina ignota Cushman and Siegfus

Plate 16, figures 31-35

Amphimorphina ignota CUSHMAN and SIEGFUS, Cushman Lab. Foram. Research Contr., vol. 15, p. 27, pl. 6, figs. 10-13, 1939.

"Test with the very earliest portion biserial, the rest of the test uniserial, compressed throughout, the earlier portions strongly so, last-formed chambers in the adult only slightly compressed, early portion with the periphery keeled, in the last chambers in the adult rounded, initial end rounded, apertural end truncate; chambers in the early portion obscured by the ornamentation, not inflated, later ones in the adult slightly inflated and the sutures distinct, slightly depressed; wall ornamented with distinct plate-like longitudinal costae few in number in the earliest portion, increasing in number and less in height in the adult; aperture broadly elliptical in the adult, terminal, without a distinct lip. Length up to 2.30 mm.; diameter 0.22 to 0.35 mm."

The types are from the Canoas siltstone member of the Kreyenhagen shale, from Oil Canyon, 30 feet above upper sand, Hill 2126, W 1/4 corner, Sec. 16, T. 19 S., R. 15 E., California.

This is a unique species, differing from *A. crassa* Cushman and Bermúdez from the Eocene of Cuba in the more tapering, compressed test, the costae increasing in number and less developed in the later portion. Our species somewhat resembles that from the Eocene of Venezuela referred by Nuttall to "*Plectofrondicularia mexicana* (Cushman)," but is not the same as that species.

Genus **Nodogenerina** Cushman, 1927

Nodogenerina ? sp.

Plate 16, figure 36

The single specimen has a tapering form with inflated chambers increasing in size as added, and a terminal aperture with a distinct tooth but no tubular neck developed. It has been found only in the material from the Oil Canyon locality.

Family BULIMINIDAE

Genus **Buliminella** Cushman, 1911

Buliminella grata Parker and Bermúdez

Plate 16, figures 37a, b

Buliminella grata Parker and Bermudez, Jour. Paleontology, vol. 11, p. 515, pl. 59, figs. 6a-c, 1937.—Bermúdez, Soc. cubana historia nat. Mem., vol. 11, p. 342, 1937.—Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 27, pl. 6, figs. 14a, b, 1939.

Our specimens are from the Kreyenhagen shale of Little Tar Canyon. They have been compared with the types from the Eocene of Cuba and are identical. This species occurs in the Eocene of Bermúdez's Jabaco formation in company with *Marginulina asperuliformis* (Nuttall), *Cibicides cushmani* Nuttall, and other species described by Nuttall from the Aragón formation of Mexico. This is a very distinctive species and is considered an excellent index fossil for correlation of this portion of the Kreyenhagen with other areas.

Genus **Bulimina** d'Orbigny, 1826

Bulimina corrugata Cushman and Siegfus

Plate 16, figures 38a, b

Bulimina corrugata Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 11, p. 92, pl. 14, figs. 7a, b, 1935.—Cushman, Cushman Lab. Foram. Research Contr., vol. 15, p. 64, 1939.

"Test elongate, tapering, fusiform, greatest breadth above the middle, somewhat triangular in transverse section, angles bluntly rounded; chambers indistinct except the last three which are somewhat inflated, rather low and only slightly overlapping; sutures indistinct except in the later portion where they are distinctly depressed; wall covered by the longitudinal costae which are high and sharp, running from the initial end to the base of the last-formed chamber, continuous over the sutures, last-formed chamber smooth, distinctly perforate; aperture a rather broad, elongate opening, slightly if at all curved, with a slight lip. Length 0.35 to 0.45 mm.; diameter 0.25 mm."

This is a common species in the Garza Creek section and should make a good marker for the Kreyenhagen.

Bulimina garzaensis Cushman and Siegfus

Plate 17, figures 1a, b

Bulimina garzaensis Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 11, p. 93, pl. 14, figs. 8a, b, 1935.

"Test fusiform, greatest breadth above the middle, nearly circular in transverse section, initial end subacute or acute with a short spine, apertural end usually somewhat truncately rounded; chambers fairly distinct, especially toward the apertural end where they are inflated; sutures of the earlier portion indistinct, later somewhat depressed; wall, except for the last whorl of chambers, ornamented by longitudinal costae which are largely confined to the individual chamber to form an irregular reticulate pattern of variously shaped, depressed areas; aperture somewhat longer than broad, slightly curved, with a raised lip. Length 0.50 to 1.00 mm.; diameter 0.30 to 0.65 mm."

The types are from the Canoas siltstone member of the Kreyenhagen shale in Garza Creek.

This is a much more variable species than the preceding and is much less common.

Bulimina curtissima Cushman and Siegfus

Plate 17, figures 2a, b

Bulimina curtissima Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 11, p. 93, pl. 14, figs. 9a, b, 1935.

"Test short and broad, only slightly longer than broad, fusiform in front view, greatest breadth somewhat below the middle, thence tapering to either end, initial end acute and spinose; chambers comparatively few, strongly inflated, increasing rapidly in size as added, the last whorl making a very large part of the surface of the test, much overlapping, the base with a few very short spines; sutures distinct, slightly depressed; wall smooth, finely perforate; aperture elongate, slightly curved, with a slight lip. Length 0.30 to 0.35 mm.; diameter 0.22 to 0.25 mm."

The types are from "B" member, 83 feet below top of Kreyenhagen shale, Garza Creek.

This is a peculiar short species and may be found to be a good marker for the Kreyenhagen.

Bulimina cf. B. guayabalensis Cole

Plate 16, figure 39

Bulimina guayabalensis COLE, Bull. Am. Paleontology, vol. 14, no. 51, p. 24, pl. 1, figs. 1, 2, 1927.

A number of smooth specimens, one of which is here figured, seem very close to this species described by Cole from the Eocene Guayabal formation of Mexico.

Bulimina cf. B. lirata Cushman and Parker

Plate 17, figure 3

There are specimens in the lower part of the Kreyenhagen which closely resemble the above species, described from the Eocene, 450 feet stratigraphically above the Eocene sandstone in Coal Mine Canyon, Fresno County, California.

Genus **Bolivina** d'Orbigny, 1839

Bolivina aragonensis (Nuttall)

Plate 19, figures 7, 8

Textularia aragonensis NUTTALL, Jour. Paleontology, vol. 4, p. 280, pl. 23, fig. 6, 1930.

This species was described from the Eocene Aragón formation of Mexico. The types have been restudied and found identical with our specimens. The wall is calcareous and the apertural characters also show that the species should be placed in the genus *Bolivina*.

This is another of the links connecting this material of California with that of the Aragón of Mexico.

Genus **Bifarina** Parker and Jones, 1872

Bifarina nuttalli Cushman and Siegfus

Plate 17, figures 4a, b

Loxostomum applini NUTTALL (not Plummer), Jour. Paleontology, vol. 4, p. 285, pl. 24, figs. 4, 5, 1930.

Bifarina nuttalli CUSHMAN and SIEGFUS, Cushman Lab. Foram. Research Contr., vol. 15, p. 28, pl. 6, figs. 6a, b, 1939.

"Test long and slender, gradually tapering up to about the middle, latter half with the sides nearly parallel, the earliest portion slightly compressed and biserial, later becoming circular in transverse section and the latter half uniserial; chambers distinct, slightly inflated, the basal margin distinctly crenulate, later ones only slightly overlapping; sutures distinct, later ones slightly depressed; wall in the early biserial portion with fine longitudinal costae, later uniserial portion smooth, distinctly perforate; aperture in the adult terminal, central, rounded, with a slight lip. Length 1.00 mm.; diameter 0.20 to 0.25 mm."

The types are from the Eocene Canoas siltstone member of the Kreyenhagen shale, Oil Canyon, 30 feet above upper sand (Domengine), Hill 2126, W ¼ corner, Sec. 16, T. 19 S., R. 15 E., California.

The present material has been compared with that of Dr. Nuttall from the Eocene Aragón formation of Mexico and the specimens are identical. It is not the same as *Loxostoma applini* (Plummer) (Univ. Texas Bull. 2144, p. 69, pl. 4, fig. 1, 1927) from the Midway of Texas. It differs, as noted by Nuttall, in the large number of uniserial chambers making up half of the test in the adult. The young stages resemble the Midway form from which it may possibly have been derived. It is in many respects very similar to the figure of *Bifarina adelae* Liebus, from the middle Eocene of northern Dalmatia, but the California species has a larger number of uniserial chambers. This is one of the species used to correlate this lower part of the Kreyenhagen with the Aragón formation of Mexico.

Genus **Uvigerina** d'Orbigny, 1826

Uvigerina garzaensis Cushman and Siegfus

Plate 17, figures 5a, b

Uvigerina garzaensis Cushman and Siegfus. Cushman Lab. Foram. Research Contr., vol. 15, p. 28, pl. 6, figs. 15a, b, 1939.

"Test fusiform, one and one-half to two times as long as broad, initial end rounded or subacute, apertural end tapering to an elongate, very slender neck; chambers somewhat inflated, fairly distinct in the later portion but less so in the early portion, much overlapping except near the apertural end, somewhat flattened or concave on the inner face; sutures fairly distinct, not much depressed except in the later portion; wall finely hispid throughout; aperture with an elongate, very slender neck with a distinct but only slightly developed lip. Length 0.45 to 0.55 mm.; diameter 0.23 to 0.27 mm."

The types are from the Eocene Kreyenhagen shale, 775 feet below the top, in Garza Creek, Kings County, California.

This species most closely resembles *U. elongata* Cole (Bull. Am. Paleontology, vol. 14, no. 51, p. 26, pl. 4, figs. 2, 3, 1927) from the Eocene Guayabal formation of Mexico but differs in the larger size, less elongate form, more closely set chambers, the more slender, elongate neck, and the smoother surface.

Uvigerina churchi Cushman and Siegfus

Plate 17, figures 6a, b

Uvigerina churchi Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 29, pl. 6, figs. 16a, b, 1939.

"Test about twice as long as broad, fusiform, the initial end rounded, apertural end also mostly rounded; chambers and sutures largely obscured by the surface ornamentation, last whorl of chambers slightly inflated and more distinct; wall ornamented by rather high longitudinal costae not continuous over adjacent chambers and often somewhat irregular and broken on the individual chamber; aperture large, with a very short, stout neck and very slightly developed lip. Length 0.55 to 0.70 mm.; diameter 0.30 to 0.35 mm."

The types are from the Eocene Kreyenhagen shale, 775 feet below the top, Garza Creek, Kings County, California.

This species is larger, has less conspicuous chambers and more broken costae than *U. rippensis* Cole (Bull. Am. Paleontology, vol. 14, no. 51, p. 27, pl. 2, fig. 16, 1927).

Genus **Trifarina** Cushman, 1923

Trifarina cf. **T. advena** Cushman

Plate 19, figures 9-11

The few specimens of this genus are most closely related to *T. advena* known from the upper Eocene.

Family ELLIPSOIDINIDAE

Genus **Pleurostomella** Reuss, 1860

Pleurostomella sp.

Plate 17, figure 7

Incomplete specimens of this genus, one of which is figured, occur in the upper part of the Garza Creek section. *P. alternans* Schwager is recorded by Cole (Bull. Am. Paleontology, vol. 14, no. 53, p. 213, 1928) from the Eocene Chapapote of Mexico and by Nuttall (Quart. Jour. Geol. Soc., vol. 84, p. 74, pl. 3, fig. 10, 1928) from the Eocene of Trinidad. The figure given by Nuttall resembles our figured specimen in its short, inflated chambers. This is not the same as Schwager's species from the Pliocene of Kar Nicobar, which is a much more slender, elongate species. It is probable that there is a definite species in the upper Eocene of California, Mexico, and Trindad. It also resembles *P. naranjoensis* Cushman and Bermúdez (Cushman Lab. Foram. Research Contr., vol. 13, p. 16, pl. 1, figs. 59, 60, 1937) but the chambers are more inflated in our specimens.

Pleurostomella acuta Hantken

Plate 17, figure 8

Pleurostomella acuta Hantken, K. ungar. geol. Anstalt Mitt. Jahrb., vol. 4, p. 44, pl. 13, fig. 18, 1881.

The figured specimen is very close to this species as described and figured by Hantken from the upper Eocene of Hungary. It is rare in the California material.

Pleurostomella cf. **P. rimosa** Cushman and Bermúdez

Plate 17, figure 9

A single specimen from the Kreyenhagen shale of Little Tar Canyon may be the young stage of the above species described from the Eocene of Cuba. In form it is very much like the early stages of *P. rimosa* as shown in the types, and the aperture is similar.

Pleurostomella nuttalli Cushman and Siegfus

Plate 17, figures 10, 11

Pleurostomella nuttalli Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 29, pl. 6, figs. 17, 18, 1939.

"Test elongate, slender, four or five times as long as broad, very slightly tapering, sides in the adult nearly parallel; chambers comparatively few, increasing rapidly in size and length as added, the last two making up more than half the surface of the test, alternating, but the later ones tending to become uniserial; sutures distinct, only slightly depressed, oblique; wall smooth throughout; aperture with a distinct overhanging arch. Length 0.70 to 0.80 mm.; diameter 0.12 to 0.16 mm."

The types are from the Canoas siltstone member of the Kreyenhagen shale in Little Tar Canyon, California, U.S.G.S. loc. 14437.

This is very similar to some of the specimens from the Eocene Aragón formation of Mexico referred by Nuttall (Jour. Paleontology, vol. 4, p. 286, 1930) to *P. alternans* Schwager, a name which has been widely used for many different forms from Recent to Eocene and even in the Cretaceous. *P. nuttalli* differs from *P. alternans* in the less tapering form, fewer chambers, more remote arrangement of the chambers in the adult, and the aperture in the median line.

Genus **Ellipsopleurostomella** A. Silvestri, 1903

Ellipsopleurostomella stewarti Cushman and Siegfus, n. sp.

Plate 19, figures 13, 14

Test subcylindrical to elongate fusiform, sides of the median portion nearly parallel, tapering toward the ends; chambers few, early ones biserial, last one forming nearly the whole exterior of the adult test, not inflated; sutures indistinct, not depressed; wall smooth and polished, very finely perforate; aperture terminal, elongate, slit-like with an overhanging lip. Length 0.80 to 0.85 mm.; diameter 0.35 to 0.40 mm.

Holotype (Cushman Coll. No. 36051) from the Canoas siltstone member of the Kreyenhagen shale, 14 feet above glauconite, Oil Canyon, W ¼ Sec. 16, T. 19 S., R. 15 E., Hill 2126, California.

This species differs from *Ellipsopleurostomella curta* Cushman in the more elongate, subcylindrical form, greater development of the last-formed chamber, and fewer and less prominent biserial chambers.

Genus **Nodosarella** Rzehak, 1895

Nodosarella advena Cushman and Siegfus

Plate 17, figures 12, 13a, b

Nodosarella advena Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 30, pl. 6, figs. 19, 20, 1939.

"Test elongate, straight or slightly curved, the earliest portion showing traces of a biserial condition in the obliquity of the sutures, circular in transverse section throughout; chambers distinct, inflated, four or five in number, increasing in relative height as added; sutures distinct, somewhat depressed, the early ones slightly oblique; wall smooth; aperture terminal, elongate, narrow, slightly curved, with a distinct lip, raised more on one side than on the other. Length up to 1.00 mm.; diameter 0.25 mm."

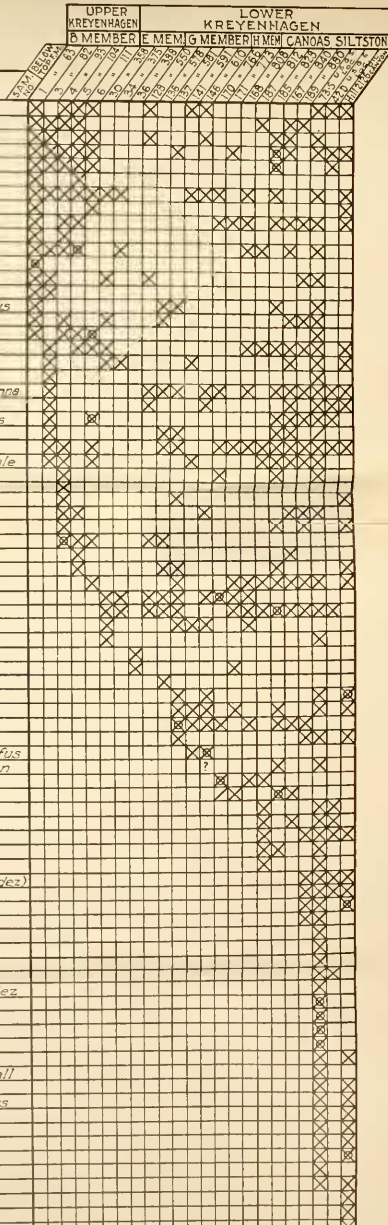
The types are from the Canoas siltstone member of the Kreyenhagen shale, in Little Tar Canyon, California. U.S.G.S. loc. 14437.

This species is close to the form recorded by Cole from the Eocene of Mexico as "*Ellipsonodosaria rotundata* (d'Orbigny)" but is not the same as that of d'Orbigny from the Miocene of the Vienna Basin. Our species does

PARTIAL CHECK LIST OF FORAMINIFERA KREYENHAGEN SHALE FORMATION

GARZA CREEK SECTION CALIFORNIA

By: J. A. Cushman & S. S. Siegfus



			Species
UPPER KREYENHAGEN	B MEMBER	1	*Bathysiphon eocenica* Cushman & G D Hanna
		2	*Hyperammina elongata* Brady
		3	*Cyclammina samanica* W. Berry
		4	*Vulvulina curta* Cushman & Siegfus
		5	*Plectina garzaensis* Cushman & Siegfus
		6	*Trochammina* (?)
		7	*Robulus alato-limbatus* (Gümbel)
		8	*Lenticulina theta*
		9	*Marginulina subbullata* Hanken
		10	*Dentalina jacksonensis* (Cushman & Applin)
		11	*Bolivinopsis direta* Cushman & Siegfus
		12	*Bulimina curtissima* Cushman & Siegfus
		13	*Ellipsonodosaria* Sp. B.
		14	*Ellipsonodosaria* Sp. C.
		15	*Pulvinulinella tenuicarinata* Cushman & Siegfus
		16	*Cassidulina globosa* Hantken
		17	*Anomalina garzaensis* Cushman & Siegfus
		18	*Dorothia principiensis* Cushman & Bermudez
		19	*Robulus welchi* Church
		20	*Pleurostomella* (?) sp.
		21	*Gyroidina soldanii* d'Orbigny var. *octocamerata* Cush. & G.D. Hanna
		22	*Eponides umbonata* (Reuss)
		23	*Asterigerina crassaformis* Cushman & Siegfus
		24	*Cibicides venezuelanus* Nuttall
		25	*Cibicides Cushmani* Nuttall
		26	*Cibicides martinezensis* Cushman & Barksdale
		27	*Robulus pseudovortex* Cole
		28	*Lagena acuticosta* Reuss
		29	*Globulina gibba* d'Orbigny
		30	*Ellipsonodosaria* sp. A.
		31	*Eponides* cf. *patelliformis* Stadnichenko
		32	*Pullenia eocenica* Cushman & Siegfus
		33	*Robulus gyroscalpum* (Stache)
		34	*Bulimina* cf. *guayabalensis* Cole
		35	*Tritaxilina colei* Cushman & Siegfus
LOWER KREYENHAGEN	E MEMBER	36	*Uvigerina garzaensis* Cushman & Siegfus
		37	*Anomalina crassisepta* Cushman & Siegfus
		38	*Plectofrondicularia* sp.
		39	*Dentalina* sp.
		40	*Spiroloculina* sp.
		41	*Planularia* cf. *markleyana* Church
	G MEMBER	42	*Hantkenina* cf. *dumblei* Weinzierl & Applin
		43	*Amphimorphina ignota* Cushman & Siegfus
		44	*Bulimina* cf. *lirata* Cushman & Parker
		45	*Bulimina corrugata* Cushman & Siegfus
		46	*Globigerina* sp.
		47	*Plectofrondicularia garzaensis* Cushman & Siegfus
		48	*Gyroidina orbicularis* d'Orbigny var. *planta* Cushman
	H	49	*Uvigerina churchi* Cushman & Siegfus
		50	*Bulimina garzaensis* Cushman & Siegfus
	CANOAS SILTSTONE MEMBER	51	*Saccorhiza ramosa* (Brady)
		52	*Ammodiscus* sp.
		53	*Marginulina asperuliformis* (Nuttall)
		54	*Nodosaria* sp.
		55	*Sigmoilina* sp.
		56	*Martinottiella* cf. *petrosa* (Cushman & Bermúdez)
		57	*Robulus* sp.
		58	*Bifarina nuttalli* Cushman & Siegfus
		59	*Ellipsoglandulina* sp.
		60	*Marginulina* sp.
		61	*Lagena* cf. *orbignyana* (Sequenza)
		62	*Buliminella grata* Parker & Bermúdez
		63	*Pluerostomella acuta* Hantken
		64	*Pluerostomella* cf. *rimosa* Cushman & Bermúdez
		65	*Pluerostomella nuttalli* Cushman & Siegfus
		66	*Nodosarella advena* Cushman & Siegfus
		67	*Nodosarella ignota* Cushman & Siegfus
		68	*Valvulineria advena* Cushman & Siegfus
		69	*Globorotalia* cf. *aragonensis* Nuttall
		70	*Anomalina dorri* Cole var. *aragonensis* Nuttall
		71	*Textularia mississippiensis* Cushman
		72	*Dentalina hispido-costata* Cushman & Siegfus
		73	*Clavulinoides* sp.
		74	*Dentalina* sp.
		75	*Dentalina* sp.
		76	*Ellipsopleurostomella stewarti* n.sp.
		77	*Trifarina* cf. *advena* Cushman
		78	*Bolivina aragonensis* (Nuttall)
		79	*Nodosaria* (Costate)
		80	*Dentalina* sp.
		81	*Dorothia* sp.

CIRCLE DENOTES SAMPLE FOR HOLOTYPE

not taper appreciably, has somewhat oblique sutures and the chambers do not enlarge as rapidly nor are they so inflated.

Nodosarella ignota Cushman and Siegfus

Plate 17, figure 14

Nodosarella ignota CUSHMAN and SIEGFUS, Cushman Lab. Foram. Research Contr., vol. 15, p. 30, pl. 6, fig. 21, 1939.

"Test elongate, tapering from the subacute initial end to the broadly rounded apertural end, circular in transverse section; chambers of the later portion distinct and subspherical, only slightly overlapping, earlier ones somewhat indistinct, more overlapping and less inflated, showing traces of a biserial condition; sutures indistinct in the earlier part, later distinct and somewhat depressed; wall ornamented by very fine longitudinal costae, dividing dichotomously as the surface area of the test increases; aperture terminal, small, elongate, with a raised lip at one side. Length 0.70 mm.; diameter 0.25 mm."

The types are from the Eocene Kreyenhagen shale, Little Tar Canyon, California. U.S.G.S. loc. 14437.

The species differs from *Ellipsonodosaria modesta* Bermúdez from the Eocene of Cuba in the shorter, broader form, fewer chambers, traces of a biserial stage, and in having an aperture which is narrow without a neck. It also resembles the form figured by Nuttall from the lower Oligocene Alazán shale of Mexico as *"Ellipsoglandulina multicostata* (Galloway and Morrey)."

Genus **Ellipsonodosaria** A. Silvestri, 1900

A number of species in the Kreyenhagen material evidently belong to *Ellipsonodosaria*. It is difficult with the fragmentary condition of the material to place most of these specifically. The apertural end is missing in most of the specimens but those that have the aperture clearly belong in this genus.

Ellipsonodosaria sp. A

Plate 17, figures 15-18

There are a number of specimens, most of them single fragmentary chambers, mostly elongate and smooth, which seem to belong with others having a bulbous proloculum and elongate second chamber. In one specimen the aperture is well preserved. Such specimens occur in the upper Eocene of Mexico and were earlier figured as *"Nodosaria ewaldi* Reuss," (Jour. Paleontology, vol. 1, p. 153, pl. 24, figs. 1, 2, 1927). Nuttall has figured similar forms from the Eocene of Trinidad as *"Nodosaria longiscata* d'Orbigny" (Quart. Jour. Geol. Soc., vol. 84, p. 181, pl. 4, fig. 13, 1928). A somewhat similar form is figured by Coryell and Embich from the upper Eocene of Panama as *"Tubinella jenningsi"* (Jour. Paleontology, vol. 11, p. 293, pl. 41, fig. 14, 1937) but the wall is described as calcareous and imperforate.

Ellipsonodosaria sp. B

Plate 17, figures 19-23

Fragmentary specimens are figured. They show elongate chambers somewhat contracted at the ends, but the apertural ends are missing. One specimen with a spinose proloculum may be the initial end. It is close to the form figured by Cushman and G. D. Hanna as "*Nodosaria* (*Dentalina*) *consobrina* d'Orbigny" (California Acad. Sci. Proc., ser. 4, vol. 16, p. 214, pl. 13, figs. 12, 13, 1927) from the upper Eocene of California. The form with a peculiarly costate proloculum (pl. 17, fig. 19) may also belong here.

Ellipsonodosaria sp. C
Plate 17, figures 24-28

Numerous specimens of a small species in the upper part of the Garza Creek section show a thick wall and distinctly hispid surface. The specimens are easily broken and except in the specimen figured none of them shows more than two chambers. In no case is the aperture well enough preserved to show its characters. It may be a good index fossil for this part of the section but its description must await the finding of better material.

Genus **Ellipsoglandulina** A. Silvestri, 1900

Ellipsoglandulina sp.
Plate 17, figure 29

The figured specimen evidently belongs to this genus although the last-formed chamber covers nearly all the previous ones. There seems to be no sign of a biserial stage and the aperture is typical for this family.

Family ROTALIIDAE

Genus **Valvulineria** Cushman, 1926

Valvulineria advena Cushman and Siegfus
Plate 17, figures 30a-c

Valvulineria advena Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 31, pl. 6, figs. 22a-c, 1939.

"Test trochoid, unequally biconvex, dorsal side less convex than the ventral, somewhat compressed, periphery rounded; chambers few, four in the adult whorl, of uniform shape, enlarging rapidly in size as added, the last-formed one making up nearly half the surface of the test; sutures distinct, slightly depressed, very slightly curved and nearly tangential on the dorsal side, ventrally nearly radial; wall smooth, conspicuously perforate; aperture a fairly large opening over the depressed umbilical region on the ventral side with a narrow but distinct overhanging lip. Length 0.50 mm.; breadth 0.45 mm.; thickness 0.30 mm."

The types are from the Eocene Kreyenhagen shale of Little Tar Canyon, California. U.S.G.S. loc. 14437.

This species differs from *V. texana* Cushman and Ellisor in the larger size, fewer chambers, and less developed lip over the aperture.

Genus **Gyroidina** d'Orbigny, 1826

Gyroidina soldanii d'Orbigny, var, **octocamerata** Cushman and G. D. Hanna
Plate 17, figures 31a-c

Gyroidina soldanii d'Orbigny var. *octocamerata* Cushman and G. D. Hanna, Proc. Calif. Acad. Sci., ser. 4, vol. 16, p. 223, pl. 14, figs. 16-18, 1927.—

Cole, Bull. Am. Paleontology, vol. 14, no. 51, p. 29, pl. 2, figs. 22-24, 1927.—Cushman and Schenck, Univ. Calif. Dept. Geol. Sci. Bull., vol. 17, p. 312, pl. 44, figs. 3-5, 1928.—Weinzierl and Applin, Jour. Paleontology, vol. 3, p. 406, 1929.—Cushman and Thomas, Jour. Paleontology, vol. 4, p. 40, pl. 4, figs. 2, 3, 1930.—Cushman, U. S. Geol. Survey Prof. Paper 181, p. 45, pl. 18, figs. 4a-c, 1935.—Cushman and McMasters, Jour. Paleontology, vol. 10, p. 514, 1936.—Bermúdez, Soc. cubana historia nat. Mem., vol. 12, p. 12, 1938.—Parr, Jour. Roy. Soc. W. Australia, vol. 24, p. 83, pl. 2, figs. 14a-c, 1938.—Howe, Louisiana Dept. Cons. Geol. Bull. 14, p. 75, pl. 9, figs. 34-36, 1939.

This variety has a rather wide distribution in the middle and upper Eocene Jackson and Claiborne groups of the Gulf Coastal Plain of the United States, Mexico, and California, and is recorded from the Eocene of Cuba and Australia. The form recorded by Cole as *G. guayabalensis* (Bull. Am. Paleontology, vol. 14, no. 51, p. 28, pl. 2, figs. 24-26, 1927) from Mexico may be the same, but his type figure seems to show a form with a still more strongly convex ventral side. The variety shows a considerable amount of variation.

Gyroidina orbicularis d'Orbigny, var. **planata** Cushman

Plate 17, figure 32

Gyroidina orbicularis d'Orbigny var. *planata* Cushman, U. S. Geol. Survey Prof. Paper 181, p. 45, pl. 18, figs. 3a-c, 1935.

Very typical specimens of this variety occur in the Kreyenhagen, especially the lower portion as exposed in Oil Canyon although it occurs at other localities as noted on the chart. The types are from the Jackson Eocene of South Carolina. Nuttall's specimens from the Eocene Aragón of Mexico referred to "*Gyroidina girardana* (Reuss)" (Jour. Paleontology, vol. 4, p. 287, 1930) probably belong to this variety.

Genus **Eponides** Montfort, 1808

Eponides cf. **E. patelliformis** Stadnichenko

Plate 17, figures 33a-c

The figured specimen from Garza Creek shows a very close relationship with the species described from the Eocene Claiborne of Texas. The species has a fairly high spire of four or more whorls and the chambers of uniform shape throughout.

Eponides umbonata (Reuss)

Plate 17, figures 35a, b

Very typical specimens of this species, with the straight radial dorsal sutures and peculiarly sigmoid ventral sutures occur in the Kreyenhagen material. Especially fine specimens occur in the collections from Little Tar Canyon. An examination of Nuttall's material from the Eocene Aragón of Mexico shows that his form is the same as that from California. According to the records, this species has a very wide range from Eocene to Recent. The

Eocene specimens are certainly very similar to those recorded from other periods.

Family AMPHISTEGINIDAE

Genus **Asterigerina** d'Orbigny, 1839

Asterigerina crassaformis Cushman and Siegfus

Plate 18, figures 1a-c

Asterigerina crassaformis Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 11, p. 94, pl. 14, figs. 10a-c, 1935.

"Test trochoid, plano-convex, dorsal side flattened, ventral side very strongly convex, especially in the central portion, completely involute, periphery acute, slightly keeled; chambers distinct, six or seven in the adult whorl, dorsally narrow, much overlapping, of rather uniform size and shape, ventrally with rhomboid supplementary chambers forming an inner ring about an umbonate central area of clear shell material; sutures very distinct, very slightly limbate, dorsally very oblique, ventrally nearly radial and slightly depressed; wall smooth, finely perforate; aperture a narrow opening in the middle of the base of the final chamber on the ventral side. Diameter 0.40 to 0.50 mm.; thickness 0.25 to 0.40 mm."

This species is common in certain parts of the Kreyenhagen from Garza Creek and should prove to be a good index fossil.

Family CHILOSTOMELLIDAE

Genus **Pullenia** Parker and Jones, 1862

Pullenia eocenica Cushman and Siegfus

Plate 18, figures 2a, b

Pullenia eocenica Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 31, pl. 7, figs. 1a, b, 1939.

"Test broadly rounded, slightly if at all compressed, close-coiled, not depressed at the umbilicus, periphery broadly rounded; chambers distinct, inflated, normally five in the adult coil, increasing slowly in size as added, apertural face low; sutures distinct, only slightly depressed; wall smooth; aperture low, at the base of the apertural face, running almost the entire width of the test. Diameter 0.40 to 0.50 mm.; thickness 0.35 to 0.45 mm."

The types are from Kreyenhagen shale, Garza Creek, Kings County, California.

This species differs from *P. bulloides* (d'Orbigny) in having normally five instead of four chambers, and the aperture extending to the limits of the chamber at the sides.

This is similar to the Eocene material from Hungary referred by Hantken (Mitth. Jahrb. k. Ungar. geol. Anstalt, vol. 4, 1875, p. 59, pl. 10, fig. 9, 1881) to d'Orbigny's species.

Family CASSIDULINIDAE

Genus **Pulvinulinella** Cushman, 1926

Pulvinulinella tenuicarinata Cushman and Siegfus

Plate 18, figures 4a-c

Pulvinulinella tenuicarinata Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 11, p. 95, pl. 14, figs. 11a-c, 1935.

"Test trochoid, biconvex, periphery acute, strongly carinate, the carina irregularly toothed; chambers somewhat obscure due to the secondary thickening over the sutures which nearly covers the chambers, about ten in the adult whorl; sutures on the ventral side slightly curved, nearly radiate, strongly limbate and fused over the umbilical area, on the dorsal side much thickened and fused, covering nearly the whole surface; wall finely perforate; aperture a small opening in the axis of coiling just ventral to the peripheral keel. Diameter 0.45 to 0.65 mm.; thickness 0.30 to 0.40 mm."

This species, described from the "G" member of the Kreyenhagen of Canoas Creek, occurs also fairly commonly in the material from Garza Creek. The specimens recorded by Nuttall as "*Pulvinulinella* (?) *culter* var. *mexicana* Cole" (Jour. Paleontology, vol. 4, p. 293, 1930) from the Eocene Aragón of Mexico seem, on comparison with topotypes from Cole's localities, closer to the present species than to Cole's variety.

Genus **Cassidulina** d'Orbigny, 1826

Cassidulina globosa Hantken

Plate 18, figures 3a, b

Cassidulina globosa Hantken, Magyar kir. földt. int. Evkönyve, vol. 4, p. 54, pl. 16, fig. 2, 1876—Liebus, Neues Jahrb., 1901, p. 125, 1901; K.-k. geol. Reichsanstalt Jahrb., vol. 56, p. 357, figs. 5a-c (in text), 1906—Martinotti, Soc. italiana sci. nat. Atti, vol. 62, p. 328, 1923.—Cushman, Cushman Lab. Foram. Research Contr., vol. 1, p. 56, pl. 9, figs. 25, 26, 1925.—Cole, Bull. Am. Paleontology, vol. 14, no. 51, p. 32, 1927.—Cushman, Jour. Paleontology, vol. 1, p. 167, pl. 26, fig. 13, 1927.—Cole, Bull. Am. Paleontology, vol. 14, no. 63, p. 216(16), 1928.—Cushman, U. S. Geol. Survey Prof. Paper 181, p. 49, pl. 20, figs. 12a, b, 1935; Cushman Lab. Foram. Research Contr., vol. 15, p. 73, 1939.

This is a small species but rather characteristic of the upper Eocene and widely distributed in Europe and America. It occurs in the Eocene of Mexico, of the Gulf Coastal Plain region of the United States, and of Georges Bank.

Family HANTKENINIDAE

Genus **Hantkenina** Cushman, 1924

Hantkenina cf. **H. dumblei** Weinzierl and Applin

Plate 17, figure 34

Hantkenina dumblei Weinzierl and Applin, Jour. Paleontology, vol. 3, p. 402, pl. 43, figs. 5a, b, 1929.—Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 32, pl. 7, fig. 2, 1939.

Although the spines on the figured specimen are broken, the angles and shape of the chambers are very similar to those of the type of *H. dumblei.*

Specimens are rare. The identity of this species seems to indicate the close correlation between this part of the Kreyenhagen and Claiborne of Texas and Mexico.

Family GLOBOROTALIIDAE

Genus **Globorotalia** Cushman, 1927

Globorotalia cf. G. aragonensis Nuttall

Plate 18, figures 5a, b

In the lower part of the Kreyenhagen shale there are specimens which are very close to the types of this species described by Nuttall from the Eocene Aragón formation of Mexico. The only appreciable difference is that our specimens have a slightly rougher, more spinose surface than the average of the types. They occurred mainly in the collections from the Canoas siltstone member in Oil Canyon and Little Tar Canyon.

Family ANOMALINIDAE

Genus **Anomalina** d'Orbigny, 1826

Anomalina garzaensis Cushman and Siegfus

Plate 18, figures 6a-c

Anomalina garzaensis Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 15, p. 32, pl. 7, figs. 3a-c, 1939.

"Test nearly planispiral in the adult, much compressed, somewhat depressed in the middle portion of both sides, periphery rounded to subacute; chambers numerous, twelve to fifteen in the adult whorl, of rather uniform shape, increasing very gradually in size as added, all visible from the dorsal side, ventral side slightly evolute; sutures distinct, slightly depressed, very slightly curved, earlier ones on the dorsal side tending to become limbate; wall distinctly perforate, smooth, except on the ventral side where the inner ends of the chambers are often slightly expanded and a definite boss appears in the umbilical region; aperture small, at the base of the last-formed chamber in the median line. Diameter 0.45 to 0.55 mm.; thickness 0.15 mm."

The types are from the Eocene, Kreyenhagen shale of Garza Creek, California.

This species differs from *A. alazanensis* Nuttall in the less flattened ventral side, somewhat broader and shorter chambers, less limbate sutures, and different ornamentation on the ventral side.

Anomalina crassisepta Cushman and Siegfus

Plate 18, figures 11a-c

Anomalina crassisepta Cushman and Siegfus, Cushman Lab. Foram. Research Contr., vol. 11, p. 95, pl. 14, figs. 12a-c, 1935.

"Test trochoid in the early stages, becoming nearly planispiral in the adult, almost completely involute, periphery in early stages subacute, in adult broadly truncate; chambers distinct, about nine in the last-formed whorl, increasing rather uniformly in size as added, ventrally slightly inflated; sutures distinct, on the ventral side slightly curved and depressed, dorsally very much thickened, especially toward the inner end, strongly curved and merging into a peripheral,